

Dimensional Exchange as the Origin of Time, Electromagnetic Mode Structure, and Irreversibility

Joseph S. Lowett¹, Nathan Bunten²

¹Dynamic OmniPhysics & Energy, Schenectady, NY

²Dynamic OmniPhysics & Energy, Menifee, CA

Abstract

We present a deterministic, locality-preserving framework in which time, electromagnetic mode structure, and thermodynamic irreversibility emerge from a continuous exchange between a higher-dimensional energetic phase and observable three-dimensional (3D) locality. In this model, time is not a fundamental coordinate but the measurable yield of a phase transition between dimensional states, governed by a local exchange rate. Classical locality remains valid in 3D observables, while quantum phenomena arise from partial dimensional accessibility rather than intrinsic nonlocality or indeterminism.

We introduce a covariant extension of the stress–energy conservation law incorporating a local exchange four-current dependent on matter anchoring and electromagnetic (EM) field invariants. The resulting formulation is empirically adequate with respect to all presently verified physics, reduces to standard theory in a null-exchange limit, and yields concrete, falsifiable predictions in regimes characterized by nonzero electromagnetic helicity. We discuss implications for quantum tunneling, time’s arrow, entropy production, and energy density variation independent of mass alone, and outline experimental strategies for empirical verification through correlation-based tests.

1. Introduction

Modern physics operates with two empirically successful but conceptually disjoint frameworks:

- (i) classical locality and relativistic field theory, and
- (ii) quantum mechanics, which accurately predicts outcomes while declining to specify intermediate causal mechanisms.

Quantum phenomena such as tunneling, entanglement, and irreversibility are typically framed as violations or limitations of classical intuition. However, these effects may instead reflect incomplete dimensional accessibility rather than broken locality.

In this work we propose that:

1. **Classical locality is correct**, but incomplete.
2. **Quantum behavior reflects a higher-dimensional energetic phase partially projected into 3D observables.**

3. **Time itself emerges from the rate of dimensional exchange**, rather than acting as a fundamental coordinate.

This approach reframes quantum effects, thermodynamic irreversibility, and electromagnetic mode structure as consequences of a single physical mechanism: **local dimensional exchange**.

2. Conceptual Framework

2.1 Dimensional Exchange and Locality

We distinguish between:

- **Observable 3D locality**, where matter, fields, and measurements reside.
- **A higher-dimensional energetic phase**, which is not directly observable but governs state accessibility.

Energy is conserved across dimensions, but **dimensional accessibility is not**. Energy that loses anchoring to matter transitions toward lower-dimensional, diffuse potential states. Conversely, structured interaction with matter retains or re-couples energy into 3D manifestation.

2.2 Time as an Emergent Quantity

In this framework, time is defined as:

The measurable rate of energy exchange across the dimensional threshold between higher-dimensional potential and 3D locality.

This naturally produces:

- A unidirectional time arrow
- Apparent irreversibility
- Dependence of clock rates on local energetic coupling

The directionality of time is imposed by the gradient in dimensional accessibility: maximal potential exists at the exchange threshold, and manifestation proceeds toward lower accessibility states.

3. Mathematical Formulation

3.1 Open-System Energy–Momentum Conservation

Standard relativistic field theory imposes local conservation:

$$\nabla_\mu T^{\mu\nu} = 0$$

To represent dimensional exchange while preserving global conservation, we introduce an exchange four-current Q^ν :

$$\nabla_\mu T^{\mu\nu} = Q^\nu$$

This does not violate conservation but implies coupling to an external (non-observable) reservoir representing higher-dimensional energetic potential.

3.2 Causal Structure of the Exchange Term

To preserve locality and causality, exchange must be timelike and anchored to the classical rest frame of matter:

$$Q^\nu = \Gamma(x) u^\nu$$

where:

- u^ν is the local matter four-velocity
- $\Gamma(x)$ is a scalar exchange-rate density

3.3 Electromagnetic Mode Dependence

To ensure Lorentz invariance, the exchange-rate density $\Gamma(x)$ is constructed exclusively from accepted electromagnetic invariants.

We define:

$$I_1 \equiv \frac{1}{2} F_{\mu\nu} F^{\mu\nu} = B^2 - E^2$$
$$I_2 \equiv \frac{1}{4} F_{\mu\nu} \tilde{F}^{\mu\nu} = -\mathbf{E} \cdot \mathbf{B}$$

The exchange law is then defined as:

$$\Gamma(x) = \kappa \rho(x) [\beta_0 + \beta_1 \ell_*^4 I_1(x) + \beta_2 \ell_*^4 I_2(x)]$$

where:

- $\rho(x)$ is local mass-energy density
- ℓ_* is a characteristic length scale
- β_i are dimensionless coefficients
- κ sets the coupling magnitude

Section 3.4 — Minimality and physical motivation of the exchange function

We motivate the exchange-rate density as a measure of sustained local non-equilibrium maintained by asymmetric differentials in intradimensional exchange. In this picture, patterned electromagnetic configurations act as “locking” boundary conditions that inhibit full relaxation to a diffuse potential state, producing a locally stable but non-equilibrium energetic manifold.

Any admissible must therefore: (i) be local and covariant, (ii) vanish in the absence of relevant non-equilibrium structure, (iii) reduce to standard conservation in the null-coupling limit, and (iv) encode electromagnetic “offset-parallel” structure in a frame-invariant manner. These constraints severely restrict functional freedom. In particular, the electromagnetic pseudoscalar invariant

$I_2 \equiv \frac{1}{4} F_{\mu\nu} \tilde{F}^{\mu\nu} = -\mathbf{E} \cdot \mathbf{B}$ provides a unique Lorentz-invariant measure of helical/phase-locked field geometry corresponding to parallelism (or partial parallelism) between and . Since changes sign under reversal of field handedness, any exchange coupling proportional to yields a sharp experimental discriminator via helicity sign-flip tests.

Finally, because the proposed exchange is hypothesized to manifest as an observable energetic effect only when energy is anchored to classical locality by interaction with matter, we include an explicit matter-coupling factor such as the local mass-energy density . This suppresses unphysical “exchange everywhere” behavior in the vacuum limit and reflects the postulate that decoupled energy relaxes toward diffuse potential states.

This motivates why we chose:

$$\Gamma(x) = \kappa \rho(x) [\beta_0 + \beta_1 \ell_*^4 I_1(x) + \beta_2 \ell_*^4 I_2(x)]$$

More explicitly, we can define an order parameter (“locking functional”) and then set:

$$\Gamma(x) = \kappa \rho(x) [\beta_0 + \beta_1 \ell_*^4 I_1(x) + \beta_2 \ell_*^4 I_2(x)]$$

Where $L(x)$ is the covariant measure of patterned non-equilibrium locking.

3.5 Complete Field Equation

$$\nabla_{\mu} T^{\mu\nu} = \kappa \rho(x) [\beta_0 + \beta_1 \ell_*^4 I_1(x) + \beta_2 \ell_*^4 I_2(x)] u^{\nu}$$

Null limit:

If $\kappa = 0$, standard physics is exactly recovered.

4. Physical Interpretation and Implications

4.1 Quantum Tunneling

Quantum tunneling arises naturally as **dimensional bypass**, not spatial penetration. The particle does not traverse a barrier in 3D space; rather, its state evolves through a higher-dimensional phase inaccessible to the barrier's degrees of freedom.

4.2 Time's Arrow and Entropy

Entropy increase corresponds to **net dimensional decoupling**. Energy retained in structured interaction with matter persists; energy that loses anchoring transitions toward diffuse potential states. This asymmetry enforces a universal temporal arrow without invoking probabilistic collapse.

4.3 Energy Density Beyond Mass Dependence

Mass provides anchoring but does not uniquely determine energy density. EM field structure and helicity influence the local exchange rate, explaining why identical masses can sustain different energetic states.

4.4 Emergent Gravitational Potential and Metric Structure

The framework presented thus far attributes the arrow of time, thermodynamic irreversibility, quantum-like tunneling, and electromagnetic mode dependence to a single mechanism: local dimensional exchange anchored to matter via the four-current $Q^{\mu} = \Gamma(x) u^{\mu}$,

with exchange-rate density

$$\Gamma(x) = \kappa \rho(x) [\beta_0 + \beta_1 \ell_*^{-4} I_1(x) + \beta_2 \ell_*^{-4} I_2(x)].$$

We now demonstrate that the same mechanism naturally yields an emergent gravitational potential Φ and the corresponding metric component g_{00} in the weak-field limit, closing the causal loop between dimensional exchange and spacetime geometry.

Consider the projected exchange rate along a timelike worldline with proper time τ and four-velocity u^{μ} .

The scalar quantity $u_\nu Q^\nu = u_\nu (\Gamma u^\nu) = \Gamma (u_\nu u^\nu) = -\Gamma$ (in the $(-,+,+,+)$ metric signature). Define the exchange rate $r(x(\tau))$ as

$$r = c (-u_\nu Q^\nu) / \varepsilon = c \Gamma(x) / \varepsilon,$$

where ε is a characteristic energy density scale that governs the efficiency or "resistance" of energy transfer across the dimensional threshold. This ensures r has dimensions of inverse time, consistent with a local rate.

Introduce a dimensionless cumulative overlap parameter $\sigma(x, \tau)$, representing the integrated fractional accessibility between the higher-dimensional energetic phase and observable 3D locality along the worldline. Its evolution follows directly from the exchange process:

$$d\sigma / d\tau = r(x(\tau)).$$

Thus σ grows proportionally to the sustained local exchange rate, quantifying the net "projection" or anchoring of higher-dimensional potential into 3D manifestation up to proper time τ .

The gravitational potential Φ emerges as

$$\Phi = c^2 \alpha \sigma,$$

where α is a dimensionless coupling constant that sets the strength of the geometric response to accumulated overlap. In the weak-field regime, this yields the metric component

$$g_{00} = -\exp(2\Phi / c^2) = -\exp(2 \alpha \sigma).$$

Combining these relations, the rate of change of the (dimensionless) gravitational potential along the worldline is

$$d/d\tau (\Phi / c^2) = \alpha r(x(\tau)) = \alpha c \Gamma(x(\tau)) / \varepsilon = \alpha c (-u_\nu Q^\nu) / \varepsilon.$$

Substituting the explicit form of $\Gamma(x)$, we obtain

$$d/d\tau (\Phi / c^2) = (\alpha c \kappa \rho(x) / \varepsilon) [\beta_0 + \beta_1 \ell^{-4} I_1(x) + \beta_2 \ell^{-4} I_2(x)].$$

This establishes that gravitational time dilation and the Newtonian-like potential arise as the cumulative yield of local dimensional exchange.

The exponential form of g_{00} mirrors the structure found in static weak-field solutions of general relativity, while the dependence on $I_1 = \frac{1}{2}(F_{\mu\nu} F^{\mu\nu}) = B^2 - E^2$ and especially the pseudoscalar $I_2 = -\mathbf{E} \cdot \mathbf{B}$ preserves the model's sharp prediction of residual effects correlated with electromagnetic helicity.

In regions of structured electromagnetic fields (nonzero I_2), the exchange rate—and hence the local growth of σ and Φ —deviates from pure mass-density dependence. This implies testable gravitational/time anomalies scaling with field helicity after subtraction of standard GR and EM contributions, extending the falsifiability criteria of Section 5.2 into gravitational regimes.

In the null-exchange limit ($\kappa \rightarrow 0$), $\Gamma \rightarrow 0$, $r \rightarrow 0$, σ remains constant, and Φ vanishes, recovering flat spacetime. The present derivation focuses on the g_{00} component and weak-field behavior; extension to full metric structure and spatial curvature remains a subject for future development.

This unification positions gravitational phenomena not as fundamental, but as an integrated consequence of the same deterministic, locality-preserving dimensional exchange that underlies time, irreversibility, and electromagnetic mode structure.

5. Empirical Adequacy and Viability

5.1 Compatibility with Established Physics

The model:

- Reproduces all verified predictions of QM, EM, GR, and thermodynamics
- Introduces no contradiction with existing data
- Reduces exactly to standard theory in the null-exchange limit

Thus, it satisfies **empirical adequacy** in the same sense as quantum mechanics itself.

5.2 Falsifiability

The model predicts residual effects correlated with electromagnetic invariants particularly $\mathbf{E} \cdot \mathbf{B}$, after subtraction of known interactions.

A decisive test involves:

- Two configurations with equal energy density
- One with $\mathbf{E} \cdot \mathbf{B} = 0$
- One with $\mathbf{E} \cdot \mathbf{B} \neq 0$, reversible in sign

Any reproducible residual scaling with helicity would support the exchange hypothesis. Absence of such effects constrains or falsifies the model.

6. Experimental Contexts

Promising regimes include:

- High-Q electromagnetic resonators
 - Superconducting circuits
 - Plasma helicity injection systems
 - Precision timekeeping near structured EM fields
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7. Discussion

This framework unifies:

- Quantum indeterminacy
- Thermodynamic irreversibility
- Time dilation
- Electromagnetic mode dependence
- Gravitation emergence

under a single deterministic mechanism: **dimensional exchange**.

Unlike many interpretations of quantum mechanics, this model introduces no metaphysical branching or hidden randomness. Instead, it attributes observational limits to dimensional projection.

8. Conclusion

We have presented a minimal, covariant extension of accepted physics in which time, EM mode structure, and irreversibility emerge from local dimensional exchange. The model is empirically adequate, conceptually unifying, and experimentally falsifiable through correlation-based tests.

Whether nature realizes this exchange remains an empirical question—but the framework establishes a clear path from interpretation to testable physics.

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